Introduction

Bill Nelson, P.E.
GLHN Architects & Engineers

Ron Schneider
Trane Commercial Systems

- Variable Flow, Chilled Water
- Solving Existing Building Problems
- Case Study - University of Arizona
- Q & A

06/18/2002

1

Introduction

Bill Nelson, P.E.
GLHN Architects & Engineers

- Variable Flow, Chilled Water
- Solving Existing Building Problems
- Case Study - University of Arizona
- Q & A

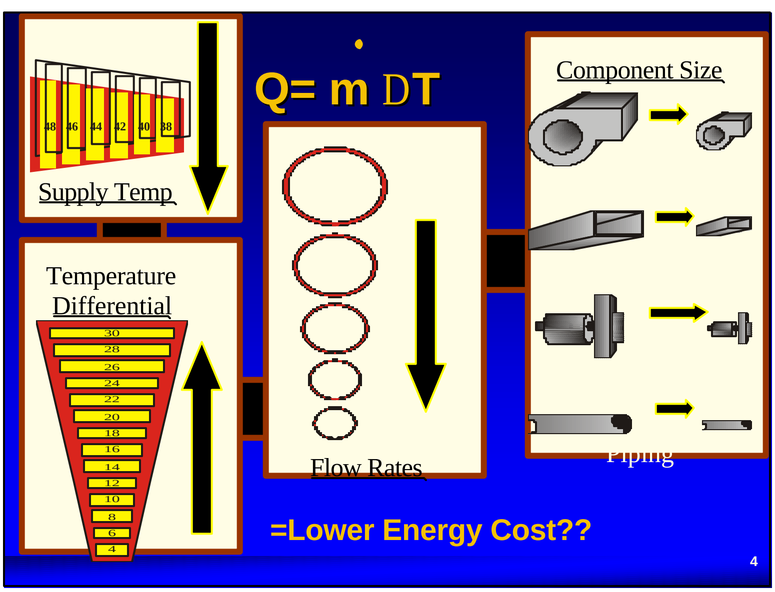
06/18/2002

2

Purpose of Today's Presentation

- Learn How To Optimize Chiller Plants to Achieve Remarkable Energy Saving and Capacity increases
- Learn Some "New Thinking" & Case Studies
- Provide Handout Material - Useful Sizing Guides

06/18/2002 3



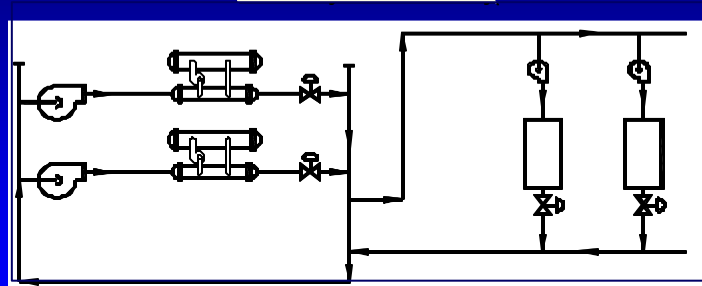
Variable Flow, Chilled Water

06/18/2002

5

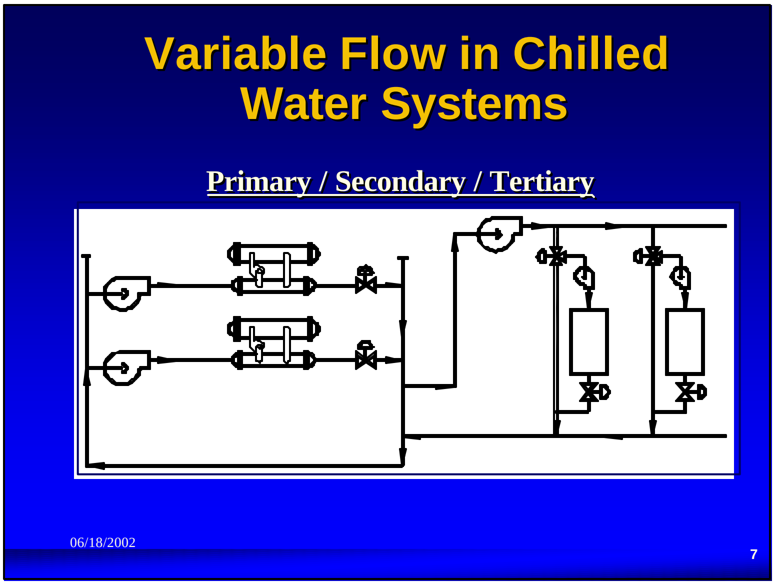
Variable Flow in Chilled Water Systems

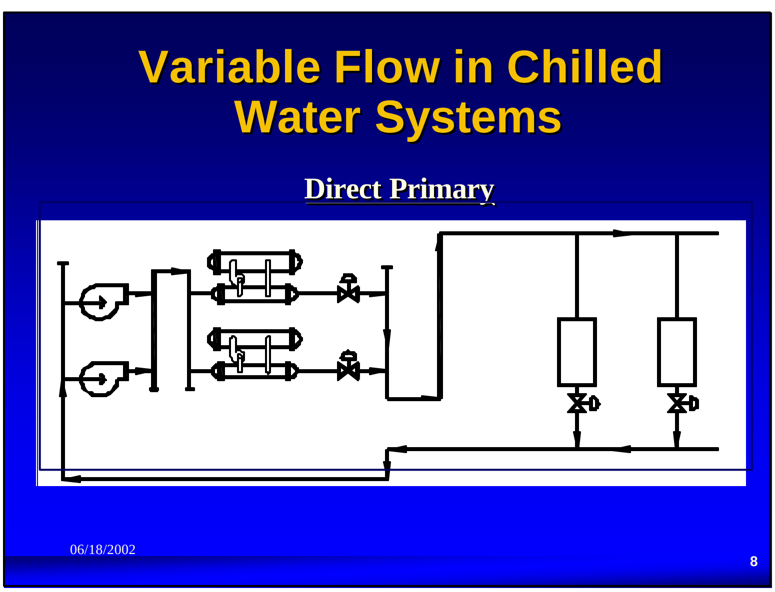
Primary / Secondary

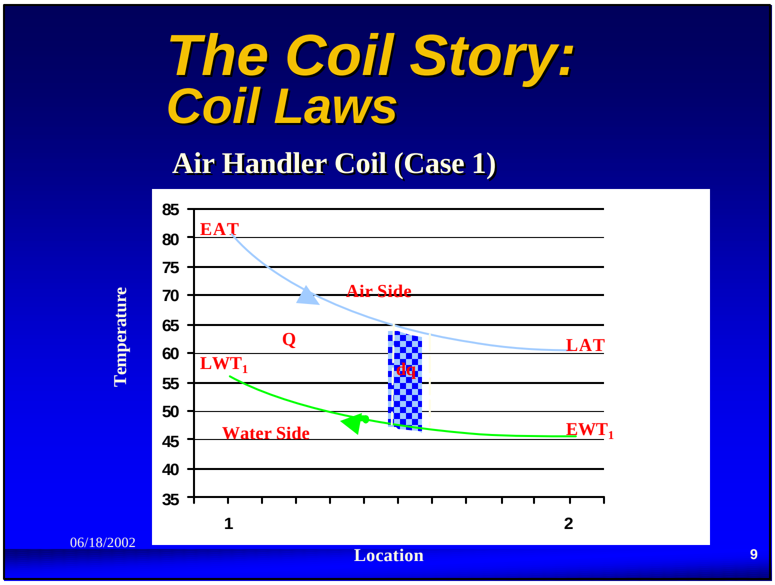


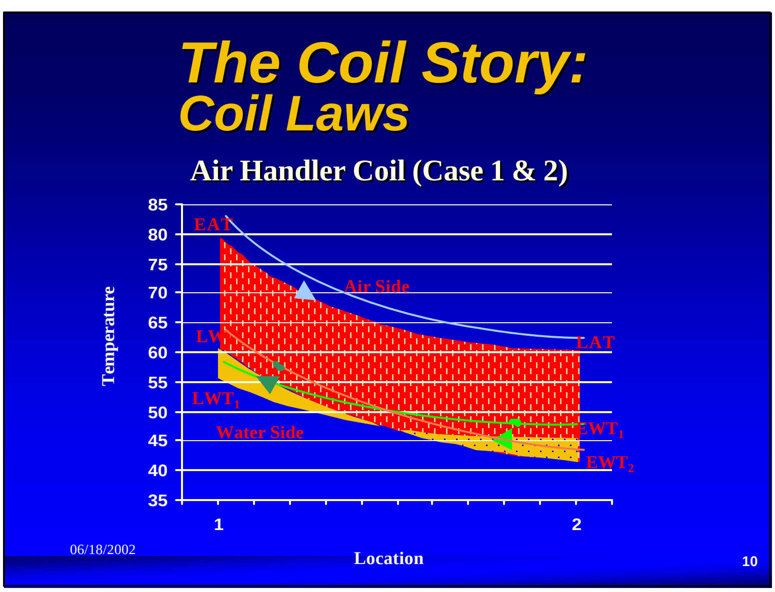
06/18/2002

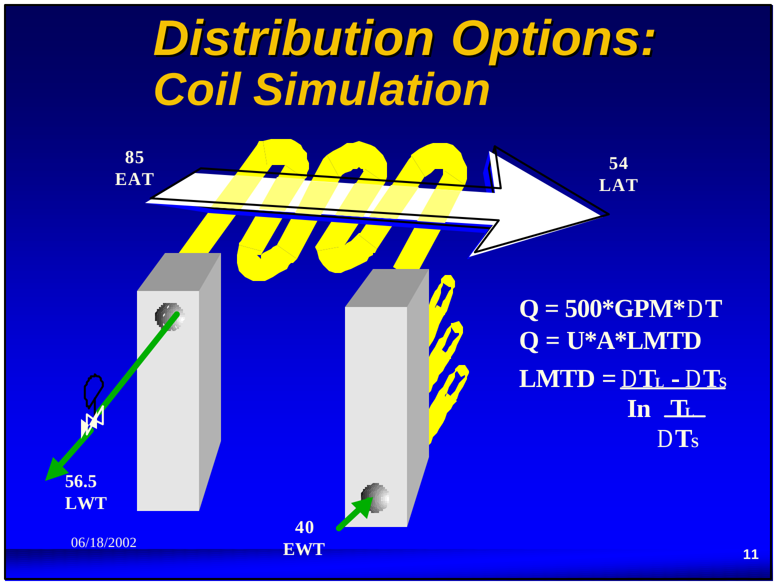
6

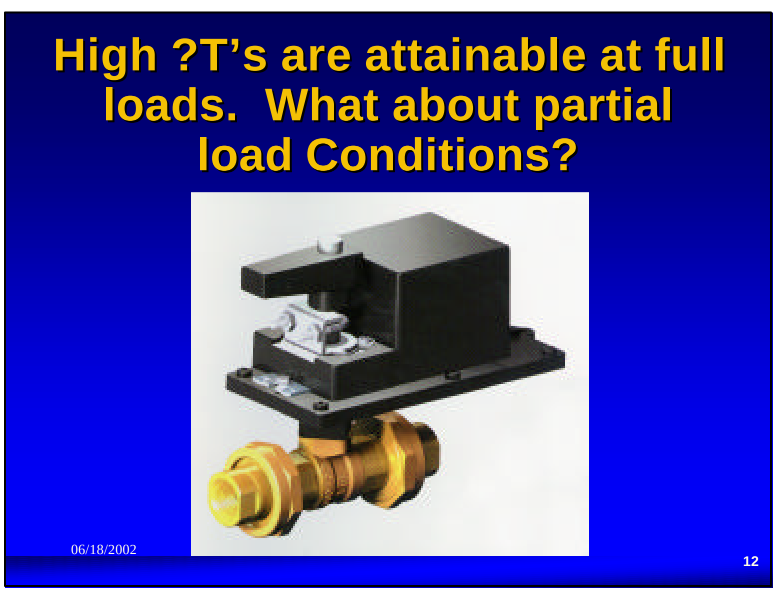

Variable Flow in Chilled Water Systems
Primary / Secondary / Tertiary
06/18/2002
7

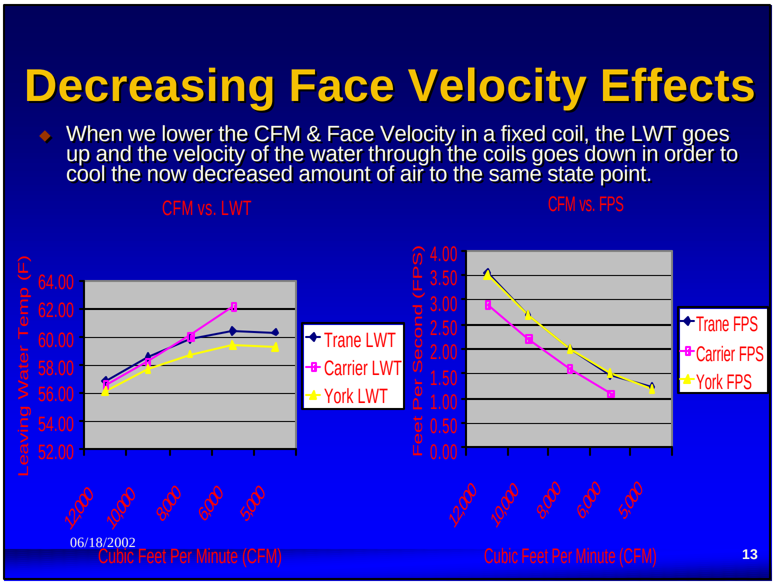

Variable Flow in Chilled Water Systems
Direct Primary
06/18/2002
8

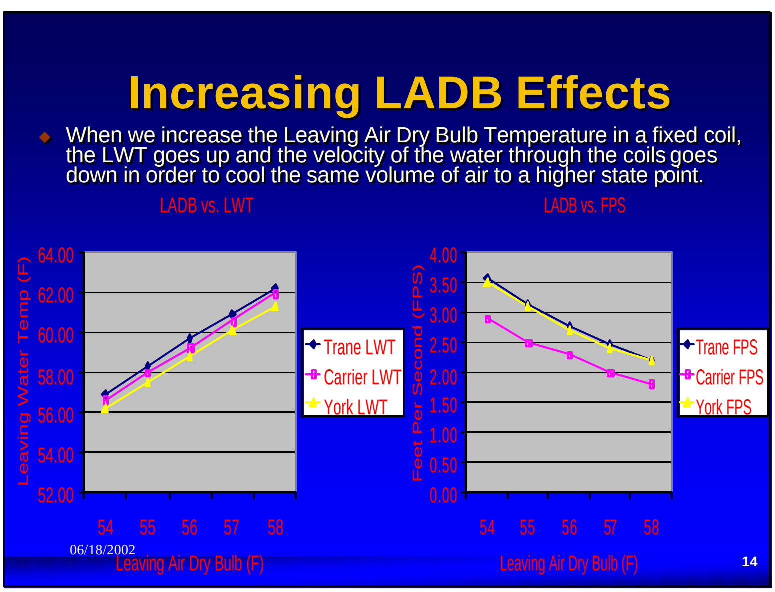

The Coil Story:
Coil Laws
Air Handler Coil (Case 1)
Temperature
85
80
75
70
65
60
55
50
45
40
35
EAT
Air Side
Q
LAT
LWT$_1$
dq
Water Side
EWT$_1$
1
2
Location
06/18/2002
9


The Coil Story:
Coil Laws
Air Handler Coil (Case 1 & 2)
Temperature
85
80
75
70
65
60
55
50
45
40
35
EAT
Air Side
LAT
LWT$_1$
Water Side
EWT$_1$
EWT$_2$
1
2
Location
06/18/2002
10


Distribution Options:
Coil Simulation
85
EAT
54
LAT
Q = 500*GPM*DT
Q = U*A*LMTD
LMTD = DTL - DTS
In TL
DTS
56.5
LWT
40
EWT
06/18/2002
11

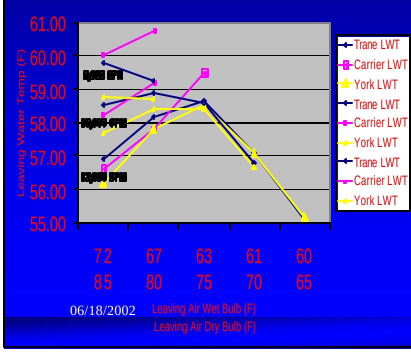

High ?T's are attainable at full loads. What about partial load Conditions?
06/18/2002
12

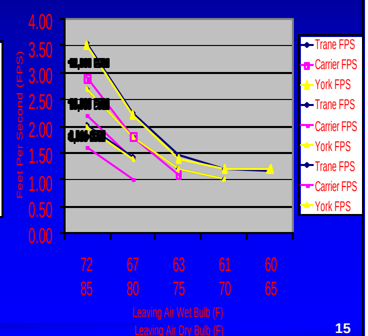

Decreasing Face Velocity Effects
When we lower the CFM & Face Velocity in a fixed coil, the LWT goes up and the velocity of the water through the coils goes down in order to cool the now decreased amount of air to the same state point.
CFM vs. LWT
Leaving Water Temp (F)
64.00
62.00
60.00
58.00
56.00
54.00
52.00
12000
10000
8000
6000
5000
Cubic Feet Per Minute (CFM)
Trane LWT
Carrier LWT
York LWT
CFM vs. FPS
Feet Per Second (FPS)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Cubic Feet Per Minute (CFM)
Trane FPS
Carrier FPS
York FPS
06/18/2002
13


Increasing LADB Effects
When we increase the Leaving Air Dry Bulb Temperature in a fixed coil, the LWT goes up and the velocity of the water through the coils goes down in order to cool the same volume of air to a higher state point.
LADB vs. LWT
Leaving Water Temp (F)
54
55
56
57
58
Leaving Air Dry Bulb (F)
Trane LWT
Carrier LWT
York LWT
LADB vs. FPS
Feet Per Second (FPS)
Leaving Air Dry Bulb (F)
Trane FPS
Carrier FPS
York FPS
06/18/2002
14

Changing Inlet Air Temperatures

- In a fixed coil, when the temperature of the outside entering air decreases, the LWT increases as the load decreases but then follows entering air temperature downwards.
- The velocity of the water through the coils drops rapidly at first, but then flattens out as the LWT decreases rapidly.



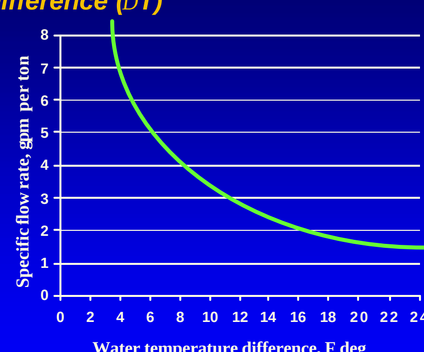


06/18/2002

15

The Coil Story:

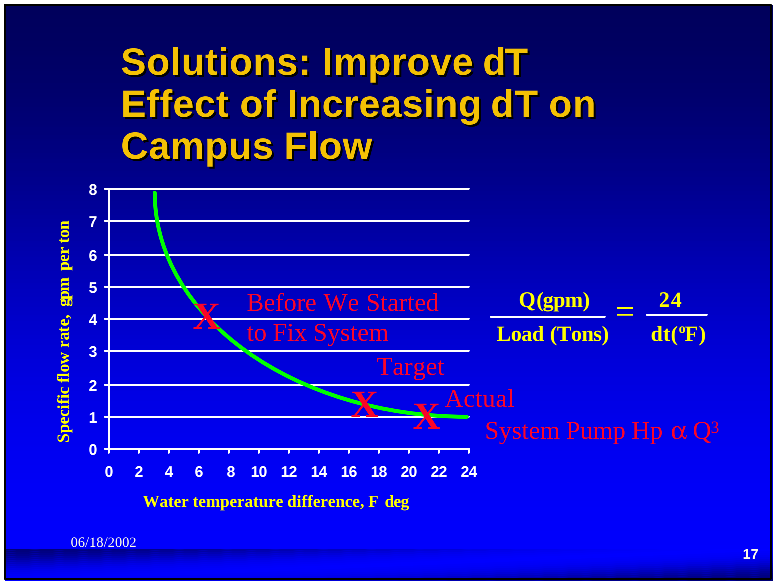
Flow Rate as a Function of Water Temperature Difference (DT)



$$\frac{Q(\text{gpm})}{\text{Load (Tons)}} = \frac{24}{dt(^{o}F)}$$

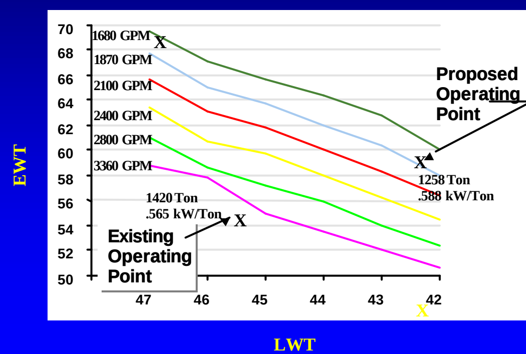
06/18/2002

16


Solutions: Improve dT
Effect of Increasing dT on Campus Flow
Specific flow rate, gpm per ton
0
1
2
3
4
5
6
7
8
0 2 4 6 8 10 12 14 16 18 20 22 24
Water temperature difference, F deg
X
Before We Started to Fix System
Target
X
Actual
X
System Pump Hp α Q³
Q(gpm) / Load (Tons) = 24 / dt(ºF)
06/18/2002
17


But What About the Chillers?
Colder leaving water means - more energy?
???
Is This True?
06/18/2002
18

Solutions: Improve dT
Effect of Increasing dT on Chiller Performance



06/18/2002

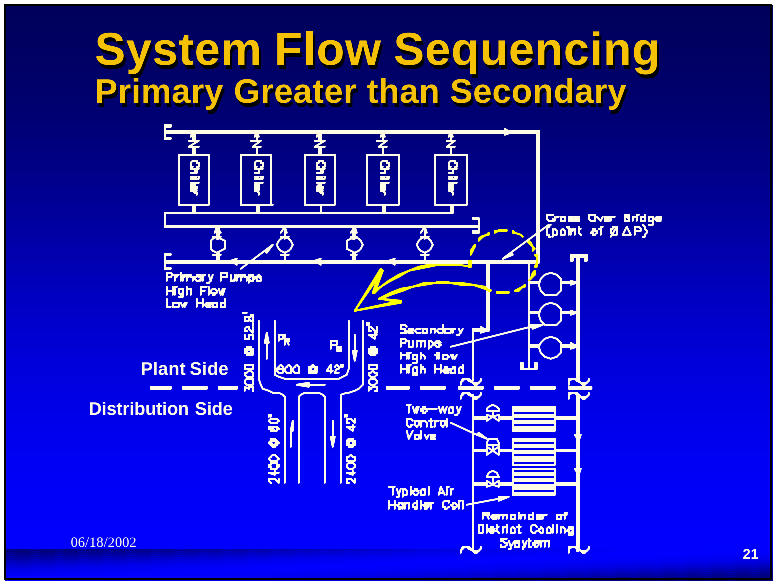
19

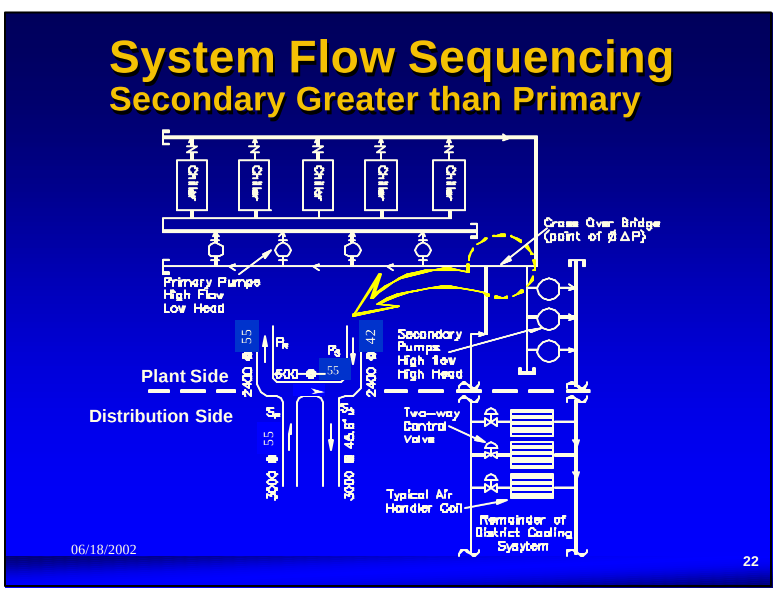
Solving Existing Building/Plant Problems

Beware of Primary/Secondary Systems

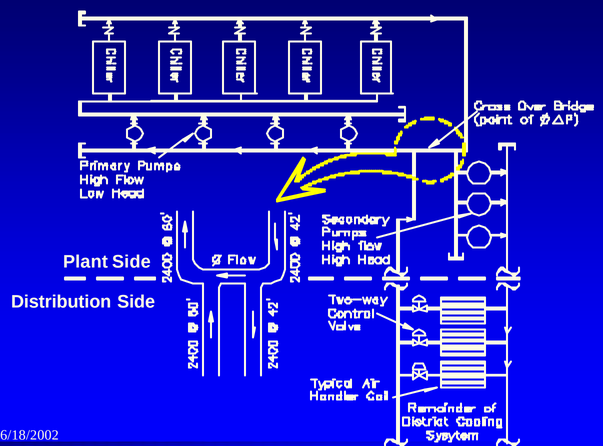
06/18/2002

20


System Flow Sequencing
Primary Greater than Secondary
Cross Over Bridge (point of Ø ΔP)
Primary Pumps
High Flow
Low Head
Secondary Pumps
High Flow
High Head
Plant Side
Distribution Side
Two-way Control Valve
Typical Air Handler Coil
Remainder of District Cooling System
06/18/2002
21


System Flow Sequencing
Secondary Greater than Primary
Cross Over Bridge (point of Ø ΔP)
Primary Pumps
High Flow
Low Head
Secondary Pumps
High Flow
High Head
Plant Side
Distribution Side
Two-way Control Valve
Typical Air Handler Coil
Remainder of District Cooling System
06/18/2002
22

System Flow Sequencing
Primary Synchronized with Secondary



06/18/2002 23

Solving Existing Building System Problems

- Cannot Get Adequate Chiller Water or Cold Enough Water To the Buildings
- Let's Look at Case Studies:

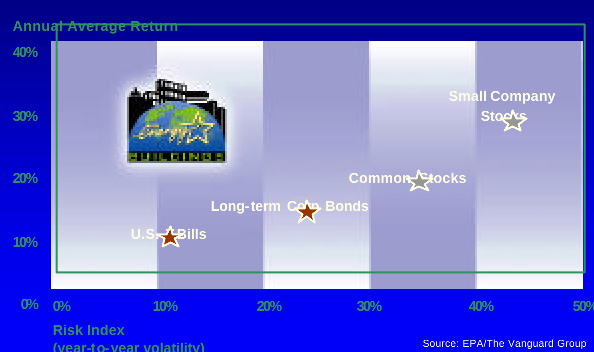
06/18/2002 24

Solving Existing Building System Problems

06/18/2002

25

Existing Buildings
Financial Opportunities



Source: EPA/The Vanguard Group

06/18/2002

26

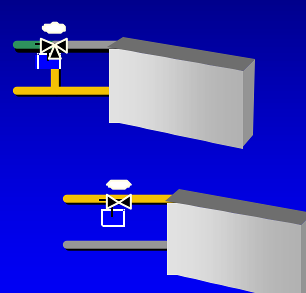
Existing Buildings
Low Flow Low Temp System Opportunities

- Waterside: aging chiller plants
  - Hydraulic opportunities
  - Energy opportunities
- Controls:
- Airside:
  - Acoustical problems?
  - Short of capacity?
- Use existing infrastructure

06/18/2002

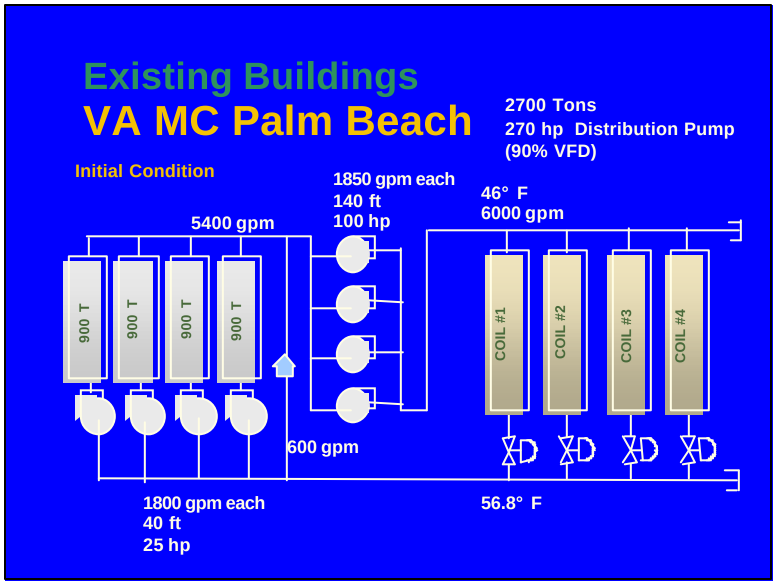
Existing Buildings
Coil DT Pirates

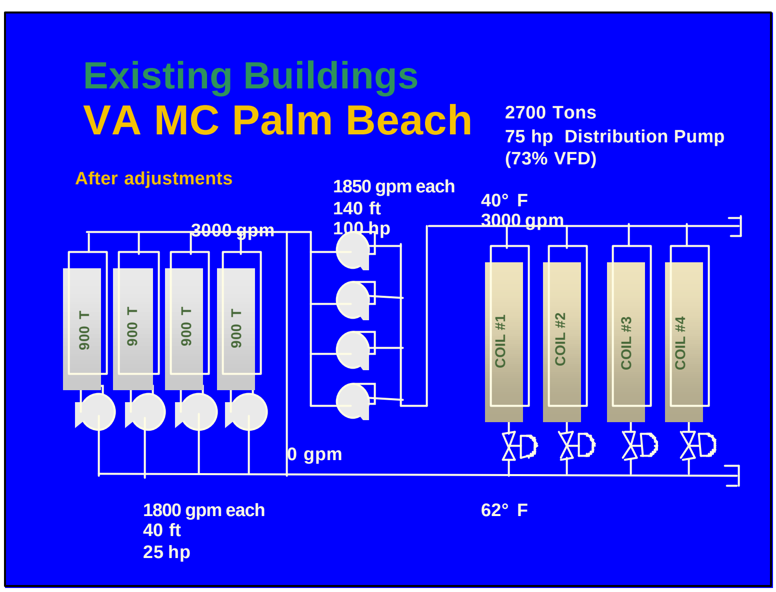
- Coil bypass
- Three-way valves
- Leakage
- Excess pressure
- Calibration
- Inaccurate control
- Pressure independent valves!



06/18/2002

28


Existing Buildings
VA MC Palm Beach
2700 Tons
270 hp Distribution Pump
(90% VFD)
Initial Condition
1850 gpm each
140 ft
100 hp
46° F
6000 gpm
5400 gpm
900 T
900 T
900 T
900 T
COIL #1
COIL #2
COIL #3
COIL #4
600 gpm
1800 gpm each
40 ft
25 hp
56.8° F


Existing Buildings
VA MC Palm Beach
2700 Tons
75 hp Distribution Pump
(73% VFD)
After adjustments
1850 gpm each
140 ft
100 hp
40° F
3000 gpm
3000 gpm
900 T
900 T
900 T
900 T
COIL #1
COIL #2
COIL #3
COIL #4
0 gpm
1800 gpm each
40 ft
25 hp
62° F

Existing Buildings
Airside Opportunities

EWT	WTR	LWT	GPM	MBH
47 °F	6.5	53.5 °F	336	1,089
46 °F	8.3	54.3 °F	263	1,089
45 °F	10.0	55.0 °F	218	1,089
44 °F	11.7	55.7 °F	186	1,089
43 °F	13.4	56.4 °F	163	1,089
42 °F	15.0	57.0 °F	146	1,089
41 °F	16.6	57.6 °F	132	1,089
40 °F	18.1	58.1 °F	120	1,089

EDB/EWB = 85 / 67
ACFM = 30,000

06/18/2002

31

Existing Buildings
Halliburton Energy, Carrollton, TX

- Waterside:
  - Chillers: (4) 1000 tons with 56 to 40 LWT
  - 1,000,000 gallon thermal storage
  - All 3-way valves changed to 2-way
- Airside Conditions:
  - AHU's: (7) #80 @ 47 LAT (@ 55 LAT >#100's)
- Controls:
  - Retrofitted to today's technology!

06/18/2002

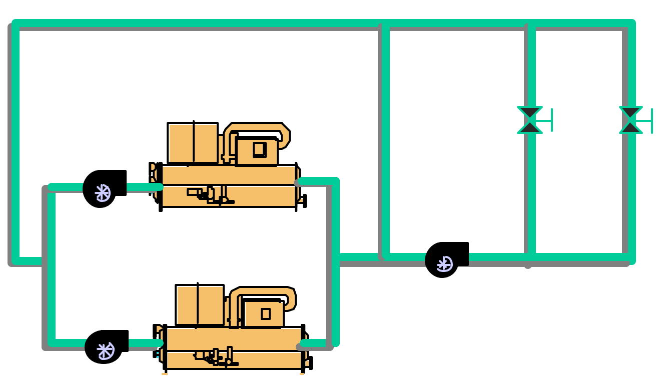
32

Existing Buildings
Current Hospital Renovation

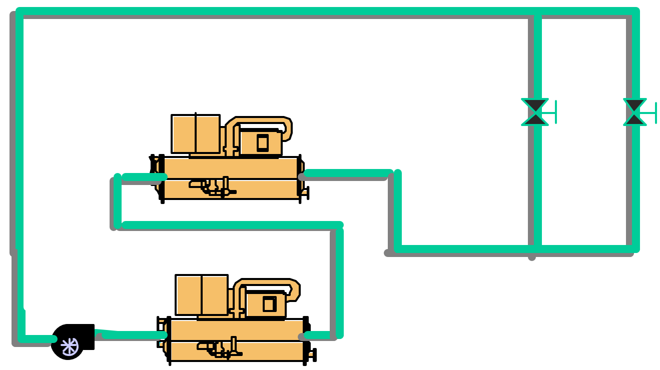
- Upgraded Design Conditions:
  - Chillers: 5200 tons with 54 to 38 LWT
  - Cooling Towers: 85 to 100
  - Converted to Variable-Primary Flow
  - Retrofitted controls to today's technology
- Savings Over Traditional Design:
  - $500,000 in first cost! (less pumps & smaller pipes)
  - $300,000 first year operating savings!

06/18/2002 33

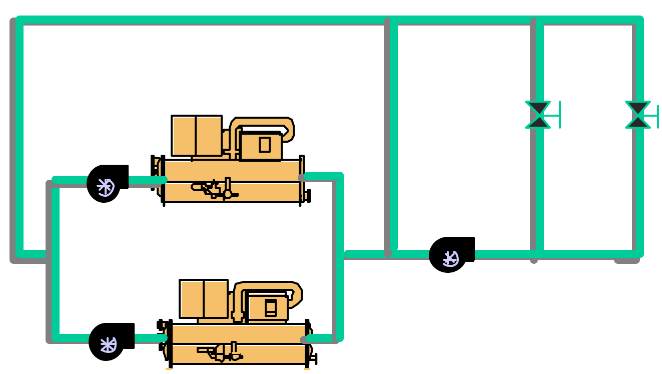
Existing Buildings
Chiller Efficiency Upgrade?

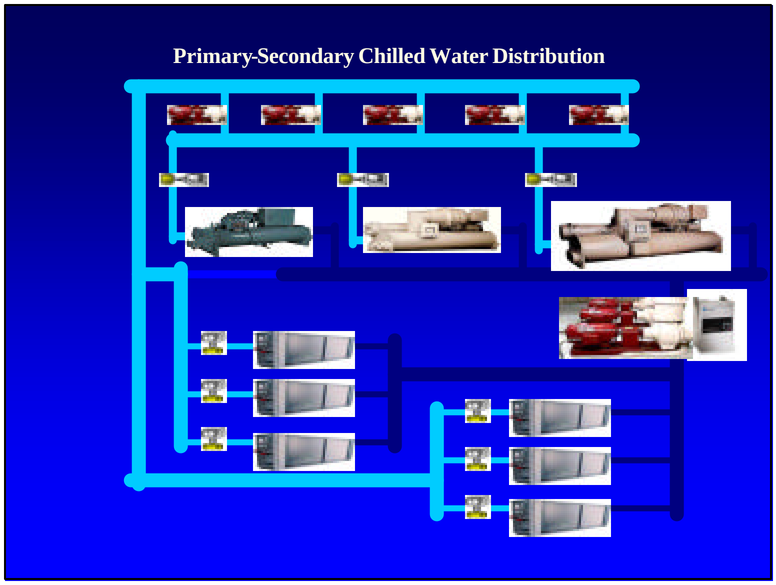


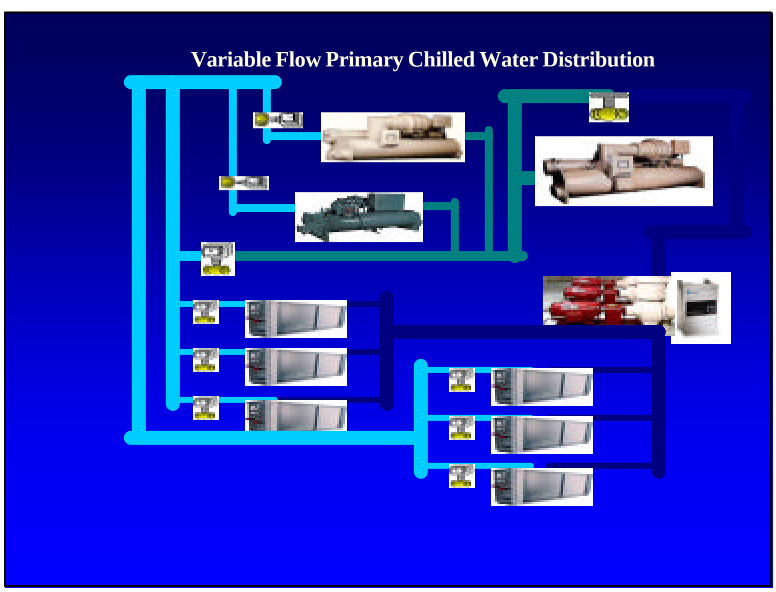
Existing Buildings
How about Series Variable Flow?



Existing Buildings
Adding an additional chiller?




Primary-Secondary Chilled Water Distribution


Variable Flow Primary Chilled Water Distribution

Existing Buildings
What about the cooling tower?

- For example, consider an existing system with:
  - Pipes
  - Pumps
  - Cooling Tower

500 tons x 3 gpm/ton = 1500 gpm
750 tons x 2 gpm/ton = 1500 gpm

Up to 50% more capacity!

06/18/2002

Existing Buildings
Memphis Office Building

- Existing Situation:
  - Could not maintain comfort if OSA was over 90 degrees!
- Owner knows one chiller has to go
- Previous Proposals:
  - Short of airflow so…
  - Replace AHU’s, ductworks, chillers, tower, etc.
- Is there a better solution?

06/18/2002 40

Existing Buildings
Memphis Office Building

- Existing Situation:
  - Could not maintain comfort if OSA was over 90 degrees!
- Previous Proposals:
  - Replace AHU’s, ductworks, chillers, etc.
- Low Flow Low Temp Solution:
  - Use existing AHU’s, ductwork, tower, etc.

Solution’s to existing buildings using low flow low temp

41

Low Flow Low Temp
New Construction Project

- J. D. Edwards, Denver, CO
- Owner occupied office campus
- Each building 190,000 sq. ft
- Budgeted and bid with rooftops!
- Owner wanted chilled water

42

Low Flow Low Temp
Waterside Installed Cost

Component	*18°F ΔT*	*10°F ΔT*	*Variance*
Labor	$26,639	$31,649	($ 5,011)
Pipe & fitting	$54,711	$88,177	($33,466)
Valves/special	$22,448	$36,977	($14,529)
Insulation	$ 5,888	$ 7,038	($ 1,150)
Pumps	$ 3,091	$ 4,519	($ 1,428)
Chillers			$ 2,760*
Cooling Towers			($ 1,280)
Electrical			($ 460)
Total			**($57,324) or $.30/sq. ft.**

Low Flow Low Temp System
Airside Installed Cost

Item	*45°F Cost*	*55°F Cost*	*Variance*
Labor	$167,956	$174,715	($ 6,759)
AHU's	$180,343	$208,520	($28,176)
VAV's	$158,374	$165,242	($ 6,868)
Sheetmetal	$ 70,095	$ 86,456	($16,362)
Subtotal	$576,768	$634,932	($58,164)
Electrical			($ 5,950)
Total			**($64,114) or $.34/sq. ft.**

Low Flow Low Temp System
Total System Installed Cost

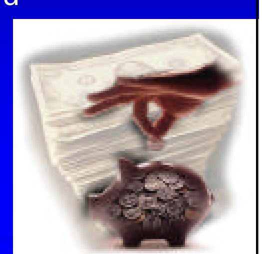
Component	*45°F Cost*	*55°F Cost*	*Variance*
Airside	$576,768	$634,932	($ 58,164)
Wetside	$111,497	$168,361	($ 56,864)
Subtotals	$688,265	$803,293	($115,028)
Electrical (airside)			($ 5,950)
Electrical (wetside)			($ 460)
Total			**($121,438) or**
			$.64/sq. ft.

06/18/2002

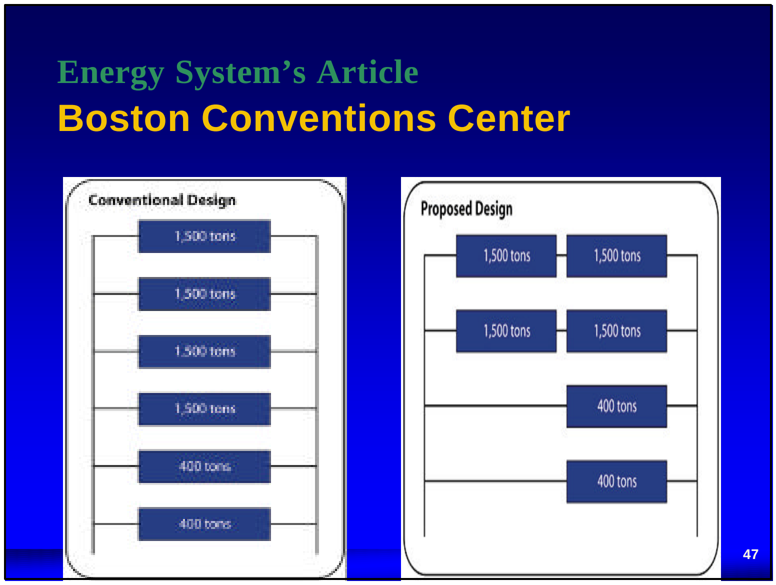
45

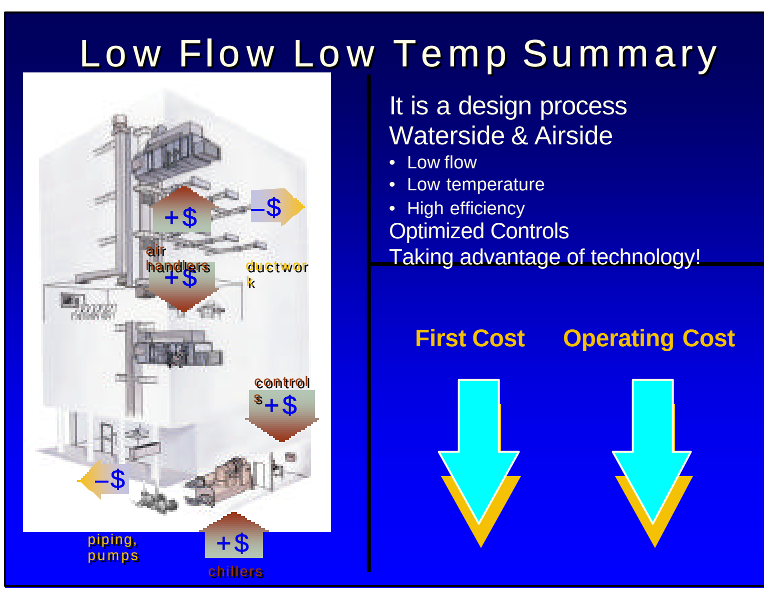
Low Flow Low Temp System
Installed Cost Savings

- $0.64 per square foot
- 6% of the entire HVAC system !!!
- $240 / Ton
- JD Edwards: ASHRAE Award



06/18/2002


Energy System's Article
Boston Conventions Center
Conventional Design
1,500 tons
1,500 tons
1,500 tons
1,500 tons
400 tons
400 tons
Proposed Design
1,500 tons
1,500 tons
1,500 tons
1,500 tons
400 tons
400 tons
47


Low Flow Low Temp Summary
It is a design process
Waterside & Airside
• Low flow
• Low temperature
• High efficiency
Optimized Controls
Taking advantage of technology!
First Cost
Operating Cost
+$
–$
air handlers
+$
ductwork
controls
+$
–$
piping, pumps
+$
chillers

Existing Buildings
Low Flow Low Temp System Opportunities?

Major University:
- Pumps: 1000 HP running!
- Chillers: 600 tons

06/18/2002

Case Studies

- University of Illinois, Urbana / Champaign
- University of Illinois, Chicago, East Campus
- University of Illinois, Springfield
- University of Chicago
- Colorado College
- **Northern Arizona University**
- University of Arizona
- University of New Mexico
- University of Arkansas
- New Mexico State University

06/18/2002

50

Chilled Water System Improvements at the University of Arizona

Presentation Outline

Background

Problems

Solutions

Results

06/18/2002

52

Background

- Campus Statistics
  - 35,000 Students
  - 12 Million sf
  - 130 Buildings
  - 5 Miles of Tunnels
  - 28,300 Tons of Refrigeration
  - 35 MW Peak
  - $16 M Electric
  - $3 M Gas

06/18/2002 53

Background

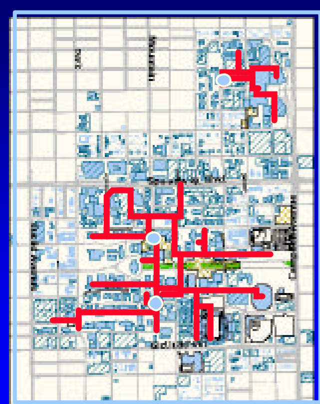
Problems

Solutions

Results

06/18/2002 54

Problem Statement: Before 1990

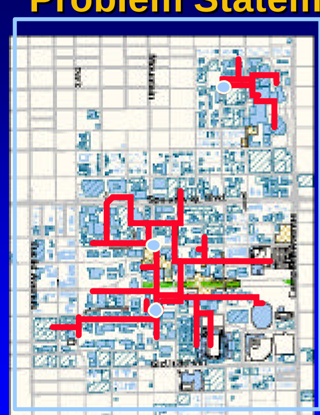


- **Technical** Problems
  - Inadequate Building Pressure at Extents
  - Insufficient Plant Capacity
  - Untreated Piping System
  - High Operational Cost
  - Trend Toward Stand Alone Building Systems

06/18/2002

55

Problem Statement: Before 1990



- **Management** Problems
  - Campus Growth Outstripping Utility System Capabilities
  - Utility Production & Distribution Efficiencies Tanking
  - Lack of a Long Term Development Plan or Vision

06/18/2002

56

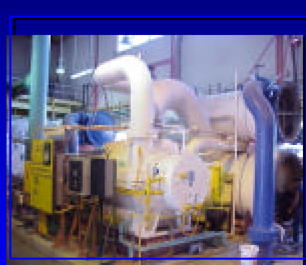
Problem Statement: Before 1990

- Inadequate Building Pressure at Extents
  - Low supply-return temperature split at buildings means high flow/ton from plant
  - High flow means high pressure drops from plant to distant buildings
  - Valves lift off near plant
  - Addition of Booster Pumps at distant buildings and Return Pressure > Supply Pressure
  - Operation of "Dead Chillers" to improve distribution flow

06/18/2002

57

Problem Statement: Before 1990



- Plant Capacity
  - Aging Chiller Fleet
  - Entirely R-11 and R-12
  - 1.0-1.2 kW/Ton
  - Plugged Tubes
  - Dedicated Chiller Piping
  - Refrigerant Leaks
    2 K lbs. R12
    1500 lbs. R11 annual loss
  - Noisy

06/18/2002

58

Problem Statement: Before 1990

- Piping system
  - No Shutdowns: Poor Isolation
  - Interior Corrosion and Scale, Rust, Plastic Bags, etc.
  - Thinwall Pipe

06/18/2002

59

Background

Problems

Solutions

Results

06/18/2002

60

Solutions: 1990 - 2001

- Phased Approach
  - Production
  - Distribution
  - Operations
  - Management
- Phase I - V Complete
- Phase VI in Planning
- Funding
  - Infrastructure Renewal
  - Support from Capital Projects
- Support of Administration
- Training

06/18/2002

61

Solutions:1990-2001

- Construct New Production Plant at weakest part of Campus (CRB)
- Improve Building System Temperature Differential and Plant flow/ton
- Interconnect Plants Physically then Operationally
- Convert distribution system from Radial Arms to Interconnected Grid
- Replace and Expand Production Capacity
  - CFC Phase Out
- Integrate Central Plant Automation

06/18/2002

62

Solutions: Construct CRB

- Initial Capacity
- Piping Configuration
- Hydronic Economizer
- Neighborhood Issues
- Noise
- Odors
- Aesthetics

06/18/2002

63

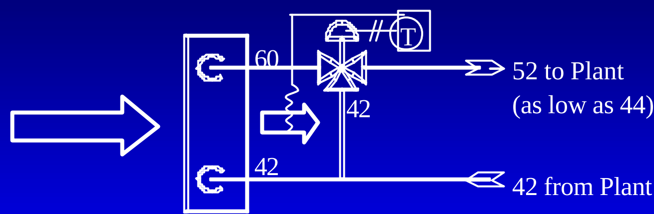
Solutions: Improve dT System Improvement Components

- Coil Control Valves
  - Replace 3-Way Valves
  - Recalibrate 2- Way Valves
  - Eliminate Other Sources of Mixing
- Pumps
  - Remove Secondary Pumps in Buildings
  - Install New VFD Pumps at Plants
  - Revise Pressure Control Philosophy
- Chillers
  - Add Controls to Allow Variable Flow
  - Lower Set Point from 45 to 42 F

06/18/2002

64

Solutions: Improve dT
Coil Control Valve Mechanics



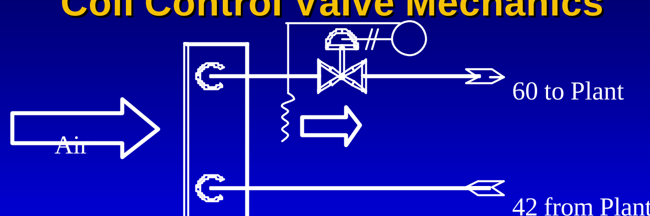
Three Way Valve

- Maintains Constant Flow to Plant
- Contaminates Return Temperature

06/18/2002

65

Solutions: Improve dT
Coil Control Valve Mechanics

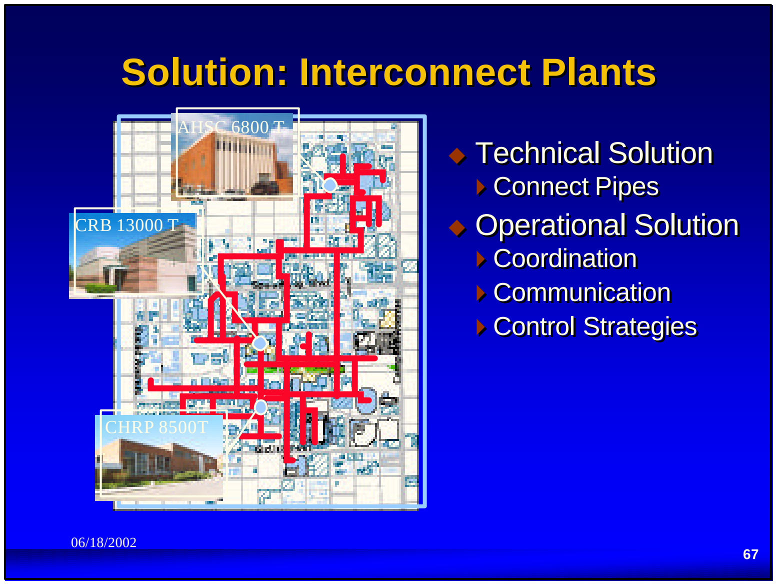


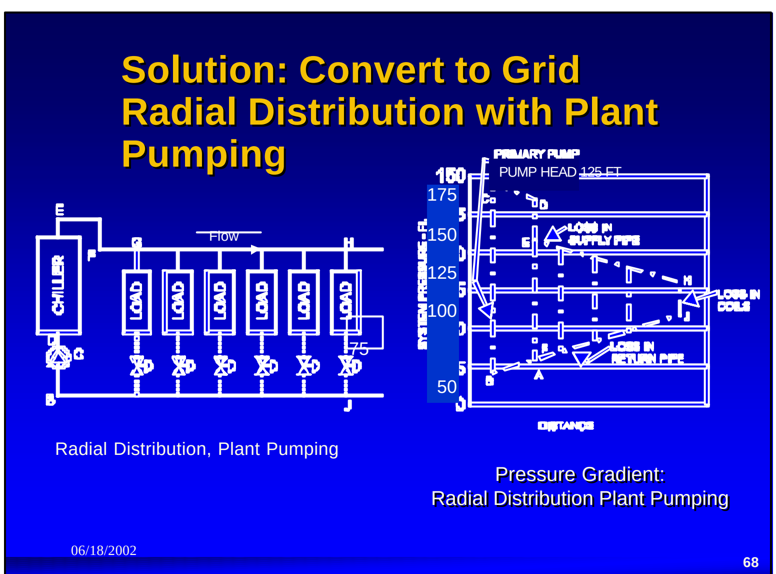
Two Way Valve

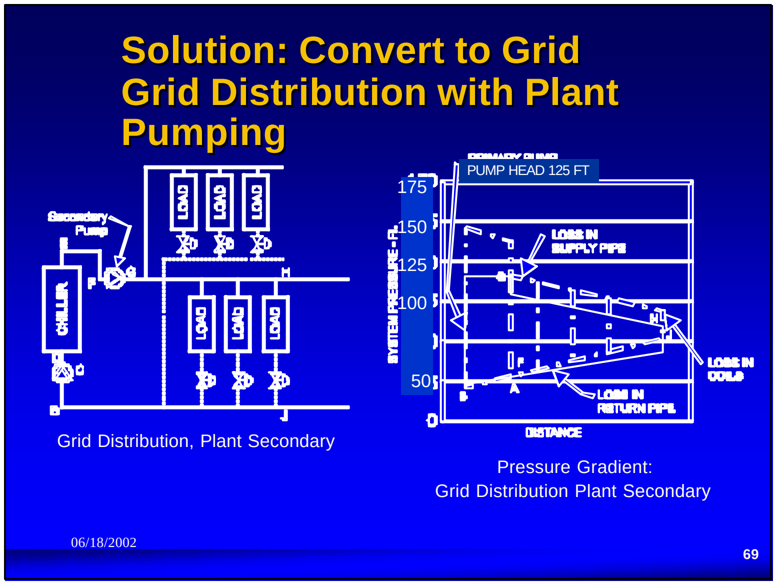
- Variable Flow
- No Mixing
- Potential to Lift Off Seat at about 20 lbs.

06/18/2002

66


Solution: Interconnect Plants
AHSC 6800 T
CRB 13000 T
CHRP 8500T
Technical Solution
Connect Pipes
Operational Solution
Coordination
Communication
Control Strategies
06/18/2002
67


Solution: Convert to Grid Radial Distribution with Plant Pumping
CHILLER
LOAD
LOAD
LOAD
LOAD
LOAD
LOAD
Flow
Radial Distribution, Plant Pumping
PRIMARY PUMP
PUMP HEAD 125 FT
175
150
125
100
75
50
LOSS IN SUPPLY PIPE
LOSS IN COILS
LOSS IN RETURN PIPE
SYSTEM PRESSURE - FT
DISTANCE
Pressure Gradient:
Radial Distribution Plant Pumping
06/18/2002
68


Solution: Convert to Grid
Grid Distribution with Plant
Pumping
Secondary Pump
CHILLER
LOAD
LOAD
LOAD
LOAD
LOAD
LOAD
Grid Distribution, Plant Secondary
PUMP HEAD 125 FT
175
150
125
100
50
0
SYSTEM PRESSURE - FT
LOSS IN SUPPLY PIPE
LOSS IN COILS
LOSS IN RETURN PIPE
DISTANCE
Pressure Gradient:
Grid Distribution Plant Secondary
06/18/2002
69

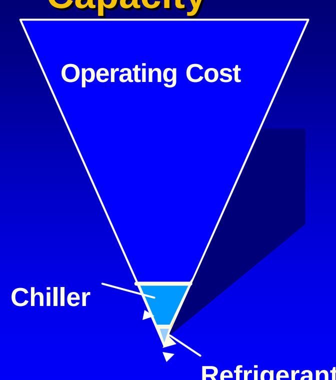

Solution: Convert to Grid
Large Diameter Direct Buried Pipe Rings Campus
Very Little Distribution Pressure Loss
Very Amenable to Load and Building Growth
Storage
06/18/2002
70

Solution: Replace and Expand Capacity

- 16,500 Tons in 3 Years
- Dual Compressor
- Single Pass Counterflow
- R 123
- Low noise
- Modular Size
- High Turn Down
- Low Pressure Drop

06/18/2002 71

Solution: Replace and Expand Capacity



- Evaluate Chiller Bids with Life Cycle Economics using Realistic Operational Profile
- High Efficiency
- Include Maintenance Costs in Life Cycle Economics

06/18/2002 72

Solution: Clean Up Water

- Side Stream Filtration
- Color Water
- Treat Water

06/18/2002 73

Background

Problems

Solutions

Results

06/18/2002 74

2001 Results

- Circa 1990
  - System Dt range
    - 4 F-11 F
  - Oldest Chiller: +25yrs
  - Avg: .85 kW/ton
  - Annual kW with xxx sf
  - CFC loss/yr- lots
  - Fouled Piping System
- Circa 2000
  - System dT range
    - 16 F-21 F
  - Oldest Chiller: 15 yr
  - Avg: .52 kW/ton
  - Annual kW with yyy s
  - CFC/ loss yr-none
  - Clean Piping System

06/18/2002 75

Future

- Ongoing Optimization
- Interface with Combined Heat and Power Operation
- Interesting Opportunities for Ice Storage at CRB
- Encourage Optimized Ownership of Systems by Operators and Maintenance People
- Continue to Look at Ways to Keep dT Up

06/18/2002 76

Elements of Success

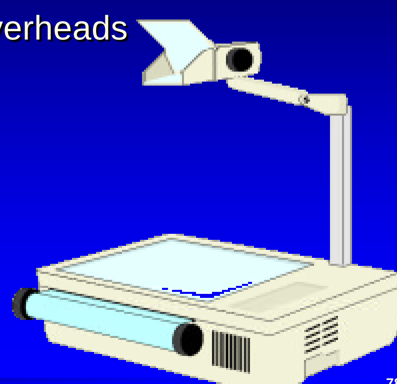
- Continuity of Administrative Support
- Implementation of Management to Overcome Operational Inertia
- Fortitude to Work Through Cost and Campus Disruption Issues to Solve Problem

06/18/2002

77

HVAC System: Chilled Water

- Capacity--See Overheads



06/18/2002

78

CHILLED WATER PIPING CAPACITY

TONS	Capacity
(1000 ft^2)	Area

BURIED PIPE		WATER SIDE TEMPERATURE RISE, ΔT GPM/TON						
Pipe Diameter (in)	GPM Vel Ft/100ft HP Cost	10°F 2.4	12°F 2.06	14°F 1.7	16°F 1.5	18°F 1.33	20°F 1.2	24°F 1.0
48	60,000 GPM 10.6 FPS 0.8'/100' 400 HP $1400/ft	25,000 (7,500)	30,000 (9,000)	35,000 (10,500)	40,000 (12,000)	45,000 (13,500)	50,000 (15,000)	60,000 (18,000)
42	40,000 GPM 9.2 FPS 0.8'/100' 200 HP $1200/ft	16,000 (4,800)	20,000 (6,000)	24,000 (7,200)	27,000 (8,000)	30,000 (9,000)	34,000 (10,000)	40,000 (12,000)
36	30,000 GPM 9.4 FPS 1.0'/100' 200 HP $1000/ft	12,500 (3,800)	15,000 (4,500)	17,500 (5,300)	20,000 (6,000)	22,500 (6,800)	25,000 (7,500)	30,000 (9,000)
30	20,000 GPM 9.1 FPS 1.1'/100' 150 HP $800/ft	8,000 (2,400)	10,000 (3,000)	12,000 (3,600)	13,000 (4,000)	15,000 (4,500)	17,000 (5,000)	20,000 (6,000)
24	12,000 GPM 8.5 FPS 1.3'/100' 120 HP $700/ft	5,000 (1,500)	6,000 (1,800)	7,000 (2,100)	8,000 (2,400)	9,000 (2,700)	10,000 (3,000)	12,000 (3,600)
18	7,000 GPM 9.5 FPS 2.0'/100' 100 HP $600/ft	3,000 (900)	3,500 (1,050)	4,000 (1,200)	4,600 (1,400)	5,200 (1,600)	6,000 (1,800)	7,000 (2,100)
16	5,000 GPM 9.0 FPS 2.8'/100' 100 HP $500/ft	2,000 (600)	2,500 750	3,000 (900)	3,500 (1,050)	3,800 (1,100)	4,000 (1,200)	5,000 (1,500)
14	4,000 GPM 9.5 FPS 3.0'/100' 100 HP $400/ft	1,700 (500)	2,000 (600)	2,400 (720)	2,700 (800)	3,000 (900)	3,400 (1,000)	4,000 (1,200)
12	3,000 GPM 8.7 FPS 3.8'/100' 75 HP $350/ft	1,250 (380)	1,500 (450)	1,800 (540)	2,000 (600)	2,300 (680)	2,500 (750)	3,000 (900)
10	2,000 GPM 8.0 FPS 3.1'/100' 40 HP $300/ft	800 (240)	1,000 (300)	1,200 (360)	1,300 (400)	1,500 (450)	1,700 (500)	2,000 (600)
8	1,200 GPM 7.7 FPS 4.0'/100' 35 HP $250/ft	500 (150)	600 (180)	700 (200)	800 (240)	900 (270)	1,000 (300)	1,200 (360)
6	600 GPM 6.7 FPS 4.0'/100' 20 HP $200/ft	250 (75)	300 (90)	350 (100)	400 (120)	450 (140)	500 (150)	600 (180)
4	200 GPM 5.0 FPS 4.0'/100' 5 HP $150/ft	80 (24)	100 (30)	120 (36)	130 (40)	150 (45)	170 (50)	200 (60)

GPM's were selected to maintain water velocities (V) below 10 fps, and pressure drop (f) below 1'/100' for large size pipes. The GPM values for smaller size pipes were selected to maintain water velocities below 7 fps, and pressure drop below 4'/100'. The velocities and friction drop values are according to Cameron. (C=100).

1000's of gross sq. ft. of building are figured at 300 GSF/ton, I.e. (10,500) indicates that approximately 10,500,000 GSF can be air-conditioned with 35,000 tons. For heavy research areas use 220 GSF/ton.

HP values to pump the water through 1000' return calculated using:

$$HP = \frac{GPM \times TDH}{3940 \times 7.5} \qquad TDH = \frac{2000}{100} \times f$$

79

STEAM SYSTEM PIPING CAPACITY

1000 lb/hr	Steam Quantity
(1000 ft^2)	Area
[HP]	Feedwater Pump HP

BURIED PIPE		INITIAL PRESSURE (psig) ΔP/100 ft · TOTAL ΔP SATURATED TEMPERATURE (°F)						
Diameter (in) Stm/Cond	Cost	15 0.4 · 4 250	30 0.6 · 8 270	50 0.8 · 12 300	100 1.2 · 20 340	125 1.6 · 26 350	150 2 · 32 370	250 3 · 50 400
24"/ 10"	$850/LF	100 (1,500) [5]	200 (3,000) [510]	300 (4,500) [40]	600 (9,000) [150]	700 (10,000) [250]	1,000 (15,000) [400]	1,500 (22,000) [1,000]
20" / 8"	$700/LF	70 (1,000) [3]	150 (2,200) [15]	200 (3,000) [30]	400 (6,000) [100]	450 (6,800) [150]	700 (10,000) [250]	950 (14,000) [600]
18" / 8 "	$650/LF	50 (750) [2]	100 (1,500) [10]	150 (2,200) [20]	300 (4,500) [75]	350 (5,200) [120]	500 (6,800) [200]	700 (10,000) [500]
16" / 6"	$600/LF	40 (600) [1]	70 (1,000) [5]	100 (1,500) [15]	200 (3,000) [50]	250 (3,800) [100]	400 (6,000) [150]	550 (8,300) [400]
14" / 6"	$550/LF	25 (380) [1]	50 (750) [4]	80 (1,200) [10]	150 (2,200) [40]	170 (2,500) [75]	250 (3,800) [100]	350 (5,200) [300]
12" / 4"	$500/LF	20 (300) [1]	40 (600) [3]	60 (900) [10]	120 (1,800) [30]	150 (2,200) [50]	200 (3,000) [75]	300 (4,500) [200]
10" / 4"	$450/LF	15 (220) [1]	25 (380) [2]	40 (600) [5]	70 (1,000) [20]	80 (1,200) [25]	120 (2,000) [50]	200 (3,000) [150]
8" / 4"	$400/LF	7 (100) [1]	15 (220) [1]	20 (300) [2]	40 (600) [10]	50 (750) [20]	70 (1,000) [30]	100 (1,500) [75]
6" / 3"	$350/LF	4 (60) [1]	7 (100) [1]	10 (150) [1]	20 (300) [5]	25 (380) [7]	40 (600) [15]	50 (750) [50]
4" / 1.5"	$300/LF	1 (15) [1]	2 (30) [1]	4 (60) [1]	6 (90) [1]	7 (100) [2]	10 (150) [4]	15 (220) [10]

Building SQFT values are based on 60Btuh/sqft peak average combined load (building heat and domestic hot water). For winter lows below +25 F: at 0 F multiply building SQFT by 0.8, at -20 F multiply building SQFT by 0.6.

Steam lines are sized to approximately 10,000 ft/min.

Condensate lines are sized to approximately yield pressure drops less than 2'/100'.

Prices shown are construction cost for a direct buried dual conduit piping system.

80

NATURAL GAS PIPING CAPACITY

1000 lb/hr (1000 ft^2) [HP] — Steam Quantity, Area, Feedwater PumpHP

Buried Pipe		Inlet Pressure D P/100 ft			
Diameter (in)	Cost ($/LF)	5 psig inlet with 1 psig drop	10 psig inlet with 1½ psig drop	30 psig inlet with 5 psig drop	60 psig inlet with 10 psig drop
6	$50 / LF	100 (1,000)	140 (1,500)	350 (3,700)	650 (7,000)
4	$40 / LF	35 (350)	50 (520)	120 (1,300)	220 (2,300)
3	$36 / LF	15 (160)	25 (260)	60 (640)	100 (1,000)
2½	$32 / LF	10 (100)	13 (150)	35 (360)	35 (700)
2	$30 / LF	6 (60)	8 (85)	20 (200)	40 (400)
1½	$28 / LF	3 (30)	4 (40)	10 (100)	20 (200)
1	$26 / LF	1 (10)	1 (10)	4 (40)	7 (75)

Building SQFT values are based on 75 Btuh/ft2 peak average combined load (building Heat and domestic hot water), and 80% combustion efficiency. For winter lows below +15 F: at 0 F multiply building SQFT by 0.8, at -20 F multiply building SQFT by 0.6.

Numbers shown are calculated for a nominal 100ft run of pipe. The energy delivered to the system may be estimated at 1040 Btu/CF. Therefore, a capacity of 20,000 CF cor-responds to (20,000 CF)*(1040 Btu/CF), or 20,800,000 Btu.

The cost to provide a boiler or other heating equipment to a stand-alone (no steam) building is approximately $2-$4 per square foot of building area.

This chart is intended to be used for obtaining an initial estimate of reauired system sizes and cost. Actual system design must be based on values obtained specifically for the project. For total project cost add A-E fees, testin, escalation, contingencies, etc.

06/18/2002

81

UNDERGROUN HIGH VOLTAGE DISTRIBUTION

MW (1000 ft^2) [A] — Power, Area, Ampacity

Wire		Voltage, Phase	
Wire Size(sets)	Cost	5KV Range	15 KV Range
Four Loops 8@500 mcm	$450/LF	N/A	25 (8,300) [1,160]
Two Loops 4@500 mcm	$240/LF	N/A	12.5 (4,200) [580]
One Loop 2@500 mcm	$130/LF	2.4 (480) [375]	8 (2,700) [370]
One Loop 2@350 mcm	$120/LF	2.0 (400) [375]	6.7 (2,200) [310]
One Loop 2@250 mcm	$100/LF	1.7 (340) [260]	5.6 (1,800) [260]
Radial 500 mcm	$80/LF	2.4 (480) [375]	8 (1,600) [370]
Radial 350 mcm	$75/LF	2 (400) [315]	6.7 (1,340) [310]
Radial 250 mcm	$70/LF	1.7 (340) [260]	5.6 (1.120) [260]
Radial 4/0	$65/LF	1.5 (300) [235]	5.2 (1,040) [240]
Radial 2/0	$62/LF	1.2 (240) [185]	4 (800) [185]
Radial 1/0	$60/LF	1 (200) [160]	3.5 (700) [165]
Radial #1	$58/LF	0.9 (180) [140]	3.1 (620) [145]
Radial #2	$56/LF	0.8 (160) [125]	2.8 (560 [130]

Ampacities shown are from the National Elec-trical Code, and are for underground ductbank, concrete encased, minimum 3 ducts. Multiple loop ampacities are reduced per the National Electrical Code. Cable is single conductor, shielded, 100% insulation level high voltage cable. Each duct contains 3 h.v. cables and a ground conductor sized per NEC.

A manhole every 500 feet.

Power factor is assumed to be 0.9.

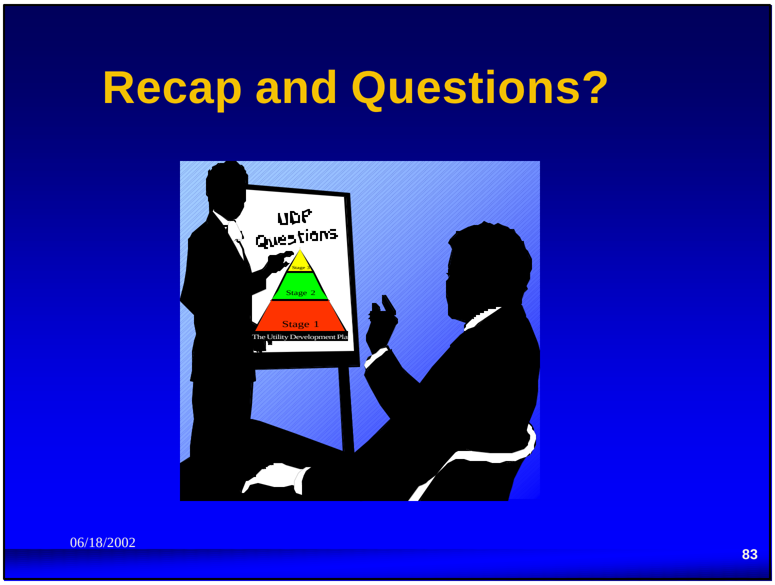
For radial systems, building area power usage is estimated at 5 W/ft^2.

For loop systems, building area power usage is estimated at 3 W/ft^2 (central plant loads not included).

Cost does not include high voltage switch at each point of use ($15,000 each).

This chart is intended to be used for obtaining an initial estimate of required system sizes and cost. Actual system design must be based on values obtained specifically for the project. For total project cost add A -E fees, testing, escalation, contingencies, etc.

82


Recap and Questions?
UDP
Questions
Stage 2
Stage 1
The Utility Development Pla
06/18/2002
83